(12) EUROPEAN PATENT APPLICATION

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(54) Polarization-independent optical waveguide switch.

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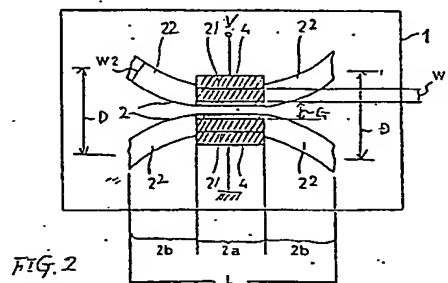
FIG. 2

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Description

POLARIZATION-INDEPENDENT OPTICAL WAVEGUIDE SWITCH

TECHNICAL FIELD

The present invention relates to an optical waveguide switch, and more particularly to an polarization-independent optical waveguide switch which utilizes a crystal substrate displaying an electro-optic effect.

BACKGROUND OF THE INVENTION

An optical waveguide switch is suitable for applications to transmission line changeover device, external modulator or the like in optical switching equipment and optical communication networks. The optical waveguide switch (hereinafter simply referred to as "optical switch" alternatively) employs an optical directional coupler consisting of an optical coupling part composed of two optical waveguides disposed adjacently with each other formed on a crystal substrate displaying an electro-optic effect and light intake/outlet parts formed as an extension on either side of the optical coupling part serving as curved optical waveguides.

Among optical waveguide switches, a polarization-independent optical waveguide switch adaptable for single-mode optical fiber links are particulary desired.

Such an optical waveguide switch is reported in Electronics Letters, Vol. 23, No. 21, pp. 1167 - 1169 (1987) by M. Kondo et al. In the optical switch, the effective refractive indices of an optical coupling part for two mutually perpendicular polarization components of a light wave propagating through the waveguides are controlled to be approximately equal. With such an arrangement, it becomes possible to carry out switching operation for a light wave with an arbitrary polarization.

Fig. 1 illustrates structural features of the Kondo et al optical waveguide switch with minor modifications. The optical switch comprises two optical waveguides 2 which form an optical coupling part 2a and light intake/outlet parts 2b and which are formed by thermally diffusing Ti into a LiNbO₃ substrate 1. Light path changeover or modulation of a light wave is carried out by applying a voltage to control electrodes 4 provided in the optical coupling part 2a. Each of the optical waveguides 2 comprises a coupling waveguide 21 which provides the coupling part 2a together with another coupling waveguide 21 of the other optical waveguide 2, and curved optical waveguides 22 serving as the intake/outlet parts 2b. The effective refractive indices of both the coupling waveguides 21 are made equal for both ordinary and extraordinary rays (or mutually orthogonal propagation components of light). Thus, complete coupling lengths of the coupling waveguides 21 which are defined as a length enough to completely shift light energy in one coupling waveguide to another through optical coupling are equal for both ordinary and extraordinary rays, resulting in a polarization-independent optical waveguide switch.

The effective refractive index of an optical waveguide is known to be determined by the size of the width and the depth of an optical waveguide and the refractive-index difference between the optical waveguide and a substrate, and the value of the effective refractive index is greater for greater values of these factors. On the other hand, the difference between the refractive index of the optical waveguide and the refractive index of the LiNbO₃ substrate generally increases with the increase in the concentration of Ti for each of two polarization components (ordinary ray and extraordinary ray) that are mutually orthogonal while the increasing tendency of the refractive-index difference is different from one polarization component to the other (See for example, J. Appl. Phys. 49(9), September 1978, pp. 4677 - 4682.) Thus, the same refractive-index differences for mutually orthogonal polarization components are achieved at a specific concentration of Ti (referred to as specific Ti concentration hereinafter) in the waveguide. The specific Ti concentration is defined as a Ti concentration in the coupling waveguides for which the differences between the refractive index of the waveguide and that of the substrate are equal for both ordinary and extraordinary rays. The specific Ti concentration depends on the width of the coupling waveguides and the gap G therebetween.

The specific Ti concentration exists in an area where the Ti concentration is relatively low compared with a Ti concentration attained in polarization-dependent optical switches. For instance, according to the referenced work by M. Kondo et al., it is the quantity of thermally diffused Ti of a Ti film with a thickness of 470 Å under the conditions of 1050°C and 8 hours. In contrast, for a polarization-dependent optical switch, a Ti film with thickness in the range of 700 to 900 Å is diffused under the same temperature and duration of diffusion so that the diffused Ti quantity in the reference is less by 45 - 20 % than the corresponding value for an ordinary or polarization-dependent optical switch. Thus, in the prior polarization-independent optical switch disclosed in the reference, a light wave is confined less strongly to the waveguides than in the prior art polarization-dependent optical switch because the difference between the refractive indices of the Ti-diffused region and the LiNbO₃ substrate is smaller in the former than in the latter.

As a general characteristic of the light wave radiation loss for curved waveguides is less when its confinement to the curved waveguides is stronger. In other words, by increasing the effective refractive index of the optical waveguides 2 the curvature of the curved portions, namely, the curved light intake/outlet parts 2b of the optical waveguides 2, can be increased, so that it becomes possible to decrease the device lengths for optical switch and modulator. For the prior art polarization-independent optical switch shown in Fig. 1, a specific Ti concentration with small amount of diffused Ti has to be used and hence the curvature of the curved light

intake part 2b of the optical waveguides cannot be made large in view of the radiation loss. Because of this limitation on the diffused amount of Ti, it is not possible to reduce the device length beyond a certain value. More definitely, it is difficult to realize small device elements while maintaining a loss of less than 1 dB/cm for a light intake part with a radius of curvature of, for example, 40 mm.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a polarization-independent optical switch which permits to realize a reduction in the length of device elements while maintaining a low loss.

According to the present invention, an optical waveguide switch comprises two optical wave-guides formed in a crystal substrate displaying an electro-optic effect, each optical waveguide being disposed closely with each other, and two elec-trodes provided respectively in each of the optical waveguides. The optical switch further comprises a directional coupler for switching optical coupling between the optical waveguides in response to a voltage applied to the electrodes, and an optical guiding part having optical waveguides connected to the optical waveguides of the directional coupler for inputting/outputting of light to the directional coupler. The width of the optical waveguides of the light guiding part is greater at least in part than the width of the optical waveguides of the optical directional coupler. The optical waveguides have a specific concentration of Ti which is thermally diffused into the substrate. The optical waveguides present the same differences between the refractive indices of the Ti diffused waveguides and the substrate for both ordinary and extraordinary rays.

In accordance with more specific features of the present invention, the optical waveguides of the optical coupler have coupling waveguides for provid-ing a complete coupling length therebetween and the optical waveguides of the guiding parts or light intake/outlet parts have curved waveguides formed to provide light intake/outlet parts. Both the coup-ling waveguides are formed with the specific Ti concentration. The width of the coupling waveguides is chosen to be smaller than the width of the curved waveguides. Thus, the effective refractive index for the curved optical waveguide corresponding to the light intake/outlet part will be greater than that for the coupling optical waveguide corresponding to the coupling part.

Therefore, the confinement of the light wave will be stronger in the optical waveguides of the light intake/outlet parts than in the optical waveguides of the optical coupling part. As a result, the radiation loss suffered by the light wave due to the light intake/outlet parts will be reduced compared with the case where the widths of the optical waveguides for the optical coupling part and the light intake/out-let parts are set to the same value W_1. Further, since low-loss intake/outlet parts can be obtained even when the curved portions of the optical waveguides are given sharper bending, it is possible to reduce the length of the device element of the optical switch. Accordingly, it is possible to realize a

small-sized matrix optical switch in which a large number of such optical switches are integrated on a single substrate. In other words, if the length of the light intake/outlet parts can be decreased for reduction in the loss, then the number of optical switches that can be integrated on a single substrate can be increased correspondingly and an expansion of the matrix size can be accomplished.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic plan view for illustrating the prior art optical switch;
Fig. 2 is a plan view for schematically showing a first embodiment of the present invention;
Figs. 3 and 4 are charts plotting the relation between the width of the curved waveguide and the radiation loss; and
Fig. 5 is a schematic plan view of a second embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, the present invention will be described in the following.

In Fig. 2, an optical waveguide switch of a first embodiment comprises two optical waveguides 2. Each waveguide 2 consists of a coupling optical waveguide 21 for a directional coupling part 2a which extend along the x-axis or y-axis of a z-cut LiNbO₃ substrate 1, where the z-axis is in the direction perpendicular to the surface of the paper, and curved waveguides 22 for light intake/outlet parts that are connected to the coupling optical wave-guides 21. First, Ti is attached to the surface of the substrate 1 to have a film of thickness of 470 Å, and with application of a photoresist on it, Ti removed by photolithography except for the portions of the Ti film above the areas where the waveguides 21 and 22 are to be formed. Then, by heating the substrate in an atmosphere at 1050°C for 8 hours, Ti is diffused into the substrate and there are obtained wave-guides 21 and 22. In the present embodiment, use was made of a mask which was to give a width of 9 μm for the waveguides 21 and a width of 11 μm for the waveguides 22. The spacing between the two waveguides 21 and the length of the waveguides 21 were selected to be 8 μm and 14 mm, respectively. On the waveguides 21 there are formed two control electrodes 4 by a sputtering method. The radius of curvature of the waveguides 22 is 40 mm.

With one of the electrodes of a directional coupler type optical switch thus formed kept grounded, if the other electrode is grounded, then the two wave-guides 21 are completely connected so that light in one of the waveguides 21 can be completely shifted to the other waveguide 21. If the other electrode is connected to a prescribed voltage V_0, the two waveguides 21 are decoupled and light propagating in each waveguide proceeds to the curved wave-guide 22 connected to each waveguide 21. The prescribed voltage V_0 is a voltage which is suffi-ciently large to decouple the light of TE mode of the waveguide. The coupling and decoupling as a result of removal and application of the voltage are caused by an electro-optic effect of the crystals and are

based on the changes in the refractive index of the crystals due to electric field. The loss in the light intake/outlet part 2b turned out to be 0.9 dB/cm which is lower than a loss of 2 dB/cm attained in a structure having the same width W_1 over the optical waveguides 21 and 22.

Fig. 3 shows plots of radiation loss against the width W_2 of the curved waveguides 22 for the case of fixing the dimension of the optical coupling part to be identical to the case of the first embodiment ($W_1 = 9 \mu m$), with radius of curvature of the light intake/outlet part as the parameter. From the figure, it clearly shows that the addition loss can be reduced by increasing the width of the optical waveguides.

Fig. 4 shows plots of the radiation loss of the optical waveguides 22, with the radius of curvature of the waveguides 22 as the parameter, for the case where the value W_1 of the optical waveguides 21 is 6 μm and the gap G between the waveguides 21 is 8 μm. In this case, the conditions for diffusion to realize the specific Ti concentration were Ti film thickness of 630 Å and an atmosphere of wet air at 1050°C for 8 hours. As is clear from the figure, in contrast, for example, to the loss of 2.6 dB/cm for the radius of curvature of 40 mm amd the width W_2 of the curved waveguides having the same value of 6 μm as the width W_1 of the coupling part, a loss of 0.8 dB/cm can be realized by taking W_2 to be 9 μm.

This value of the radiation loss is comparable to the loss of 0.6 - 0.8 dB/cm for an element with polarization-depend having identical dimensions as above and formed by diffusing, under the same conditions as in the above, a Ti film with thickness of about 850 Å corresponding to the Ti diffusion quantity required for the case of an optical waveguide satisfying the single mode condition and the strongest confinement of the light wave mode. Therefore, it can be confirmed that the radiation loss is reduced to a minimum achievable level by means of the present invention.

As shown in the above the present invention makes it possible to realize a reduction in the length L of the device element for a polarization-independent optical switch and modulator. For example, by using the characteristic shown in Fig. 4 with the separation D between the two light intake/outlet parts 2b of 200 μm, with a change in the width of the curved optical waveguides 22 from 6 μm of the conventional structure shown in Fig. 1 to 9 μm of the present invention, a reduction of 7 mm in the device element length can be realized with approximately the same loss even when the radius of curvature is decreased from about 60 mm to about 40 mm.

Fig. 5 is a plan view for schematically illustrating an optical switch in accordance with a second embodiment of the present invention. In this embodiment, the width of the optical waveguides 22 of the light intake/outlet parts 2b is given a larger value than the width of optical waveguides 21 in the optical coupling part 2a only in a portion, so that the optical waveguides 22 consist of parts with width W_2 and other parts with width W_1. With such a construction it is possible to set the complete coupling length of the optical coupling part 2a for an arbitrary polariza-

tion component to be entirely free from any influence of the form of the optical waveguides 22 of the light intake/outlet part 2b. Moreover, it is possible to obtain a polarization-independent optical switch which has low loss and small length L of the device length.

It should be mentioned in the structure of the present invention that the loss generated due to light wave mode coupling, light wave mode conversion and the like at the connection parts of two optical waveguides with different widths W_1 and W_2, has been confirmed by experiment to be extremely small, being less than 0.1 dB/cm.
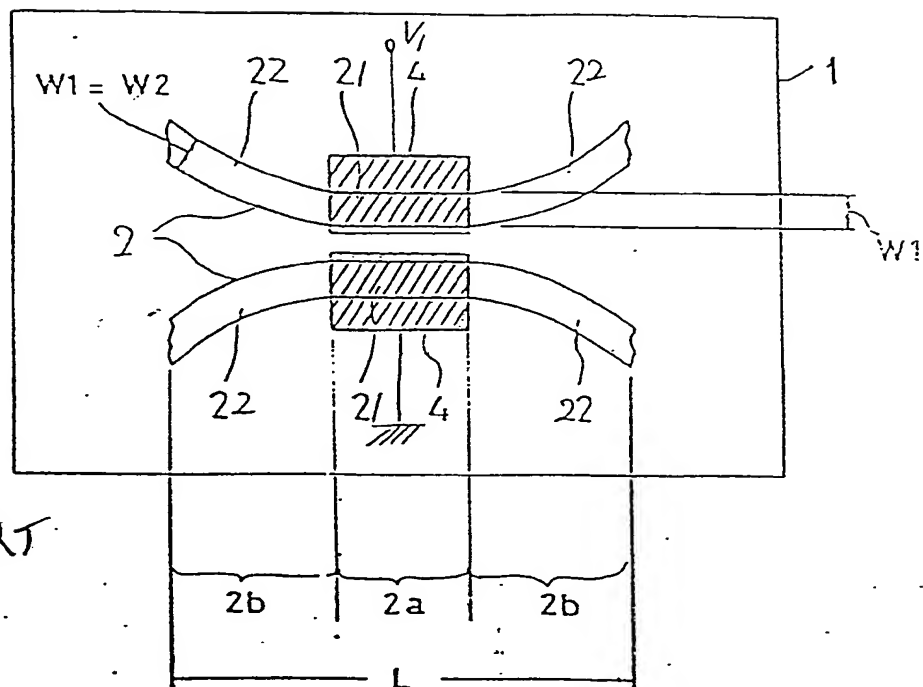
Further, the optical switch with the structure of the present invention can be operated as an optical modulator by applying a modulation signal to the control electrodes, as is well known.

As described in the foregoing, according to the present invention it is possible to obtain a polarization-independent optical switch with low loss and small length of device element by making the width of the optical waveguides of the light intake/outlet parts consisting of curved optical waveguides greater than the width of the optical waveguides of the optical coupling part.

Although the above embodiments are described with a LiNbO₃ crystal substrate, use can be made of other materials such as LiTaO₃ and compound semiconductor materials.

Claims

An optical switch comprising two optical waveguides (2) formed in a crystal substrate (1) exhibiting an electro-optic effect and disposed close to each other, and two electrodes (4) provided one on each of the optical waveguides (2), the optical switch forming a directional coupler (2a) for switching the optical coupling between the optical waveguides (2) in response to a voltage applied between the electrodes (4), and optical guiding parts (2b) having optical waveguide sections (22) connected to the optical waveguide sections (21) of the directional coupler (2a) for inputting/outputting light to the directional coupler, wherein the width (W2) of the optical waveguide sections (22) of the guiding parts (2b) is greater at least in part than the width (W1) of the optical waveguide sections (21) of the directional coupler (2a).
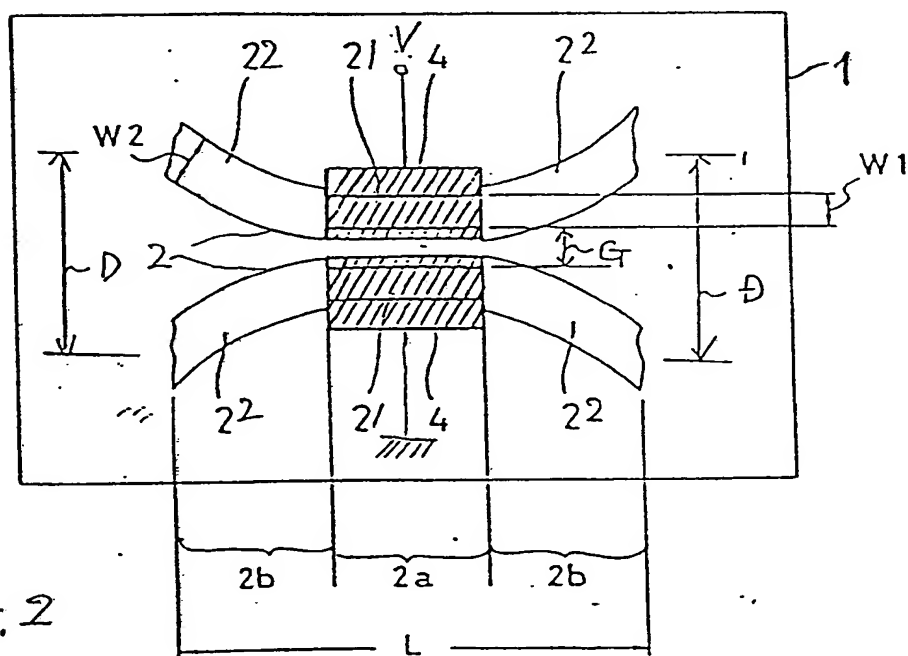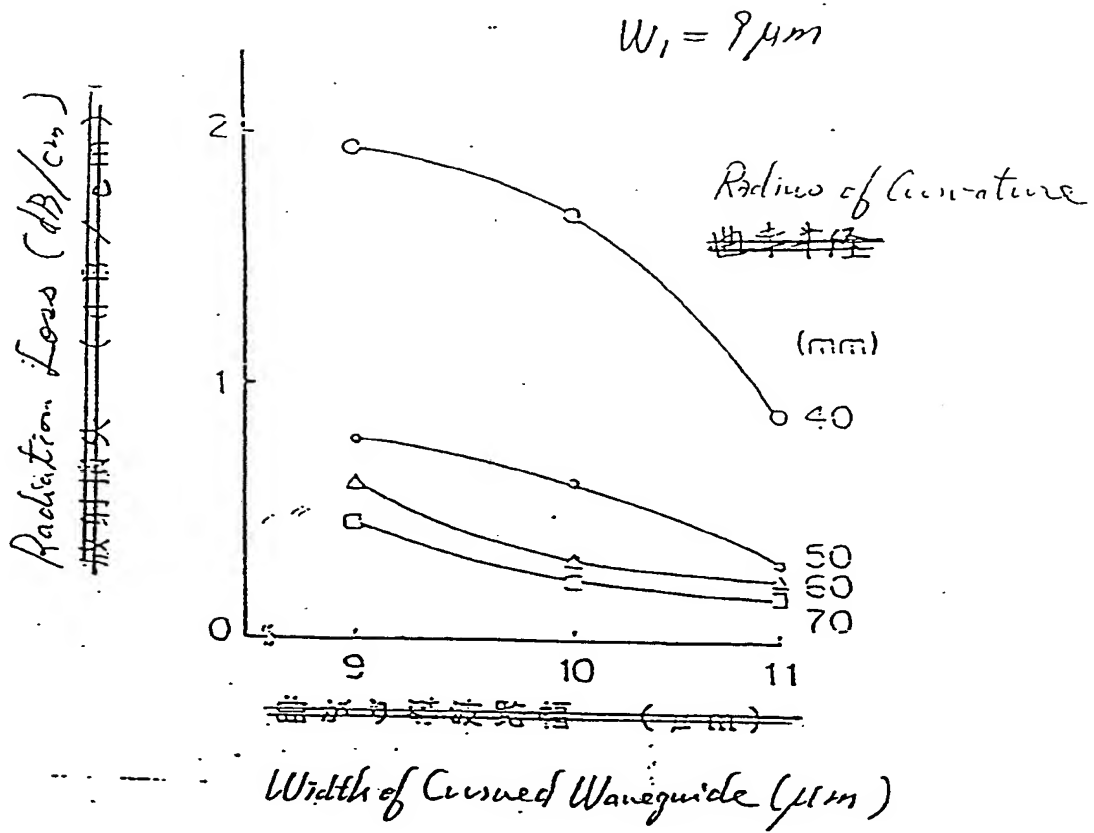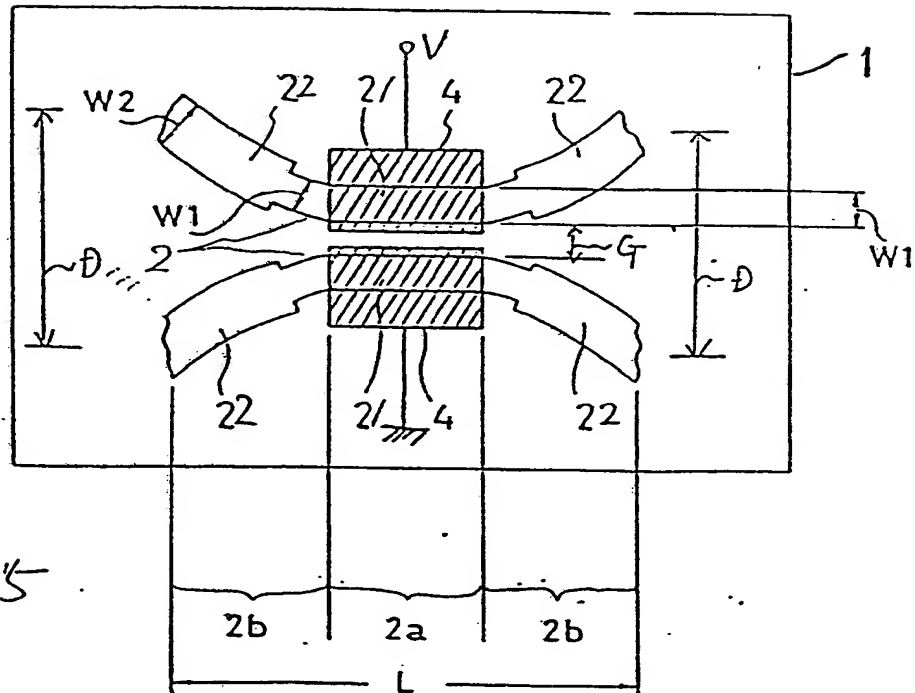
W1 = W2

22 21 V 4 22

1

2

W1

PRIOR ART

FIG. 1

22 21 4 22

2b 2a 2b

L

22 21 V 4 2²

1

W2

W1

D 2

G

D

22 21 4 22

2b 2a 2b

FIG. 2

L

$W_1 = 9 \mu m$

Radiation Loss (dB/cm)

Radius of Curvature

(mm)

40

50
60
70

9   10   11

Width of Curved Waveguide (μm)

FIG. 3

FIG. 5

$W_1 = 6 \mu m$

Radius of Curvature.
曲率半径

(mm)

→ 30
○ 40
△ 50
□ 60

Radiation Loss (dB/cm)
放射損失 (dB/cm)

曲がり導波路幅 (μm)

Width of Curved Waveguide (μm)

FIG. 4

(12) # EUROPEAN PATENT APPLICATION

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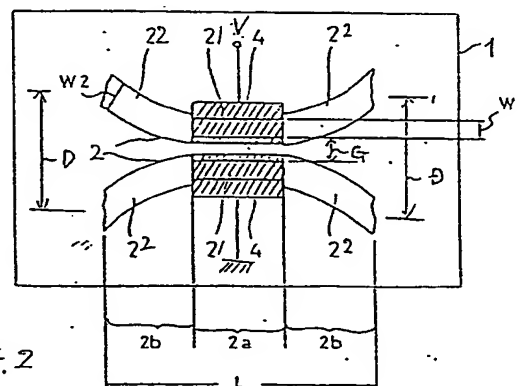
FIG. 2

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
D,Y	ELECTRONICS LETTERS, vol. 23, no. 21, 8th October 1987, pages 1167-1169, Stevenage, Herts, GB; M. KONDO et al.: "Low-drive-voltage and low-loss polarisation-independent LiNbO3 optical waveguide switches" * Page 1168, column 1, lines 8-19; figure 1 *	1	G 02 F 1/29
Y	IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-35, no. 8, August 1987, pages 681-687, IEEE, New York, US; J. RODRIGUEZ et al.: "Wide-band directional couplers in dielectric waveguide" * Page 684, column 2, line 20 - page 685, column 1, line 17; figure 2 *	1	
A	IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-30, no. 10, October 1982, pages 1747-1753, IEEE, New York, US; M. KONDO et al.: "Integrated optical switch matrix for single-mode fiber networks" * Abstract; page 1750, column 2, lines 20-37 *	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

G 02 F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11-08-1989	LOFFREDO A.

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